Magnetosphere Multiscale Mission

Radiation Requirements

DRAFT

October 11, 2000

Table of Contents

1 Radiation Environment

This section gives the total ionizing dose, non-ionizing displacement damage dose, and single event effects (SEEs) requirements for the space radiation environment.

1.1 Component Total Ionizing Dose (TID) Specification

No effect due to TID may cause permanent damage to or degradation of a system or subsystem.

Components or circuits shall be designed to be immune to TID induced performance degradation that would induce system or subsystem functional failures, anomalies, or outages which are catastrophic or require ground intervention to correct. A component is immune to TID effects if it's parametrics and functionality remain unchanged after 500krad(Si), as demonstrated by Co-60 testing as per MIL-STD-883 Method 1019.5.

If component test data does not exist, ground testing is required. For commercial components, testing is required on the flight procurement lot. All testing must follow Co-60 testing as per MIL-STD-883 Method 1019.5.

For any component that is estimated to have on-orbit performance degradation due to TID, an analysis must be preformed to show that this degradation does not cause damage to or induce-degradation of system or subsystem performance. Alternatively, protective circuitry must be added to eliminate the possibility of damage to or degradation of system or subsystem performance, and must be verified by analysis or test.

TID environment specifications (top-level shielding is assumed to be 100 mils equivalent Al):

- The top-level TID requirement to be used for analysis for the 2-year MMS mission, beginning in 2006, is given by the dose-depth curve in Figure 3-5 and Table A-1. The following missions phase duration have been considered: Phase 1: 10 months, Phase 2: 4 months, Phase 3: 3 months, Phase 4: 7 months.
- A radiation design margin of 7 will be used on all environment estimates when considering its effects on any linear bipolar and BiCMOS components, and radiation design margin of 2 will be used on all environment estimates when considering its effects on any other component.
- From top-level shielding requirement of 100 mils equivalent Al and the data in Figure 3-5, the top level TID requirement for linear bipolar and BiCMOS components is 500 krad-Si and for all other components it is 148 krad-Si.

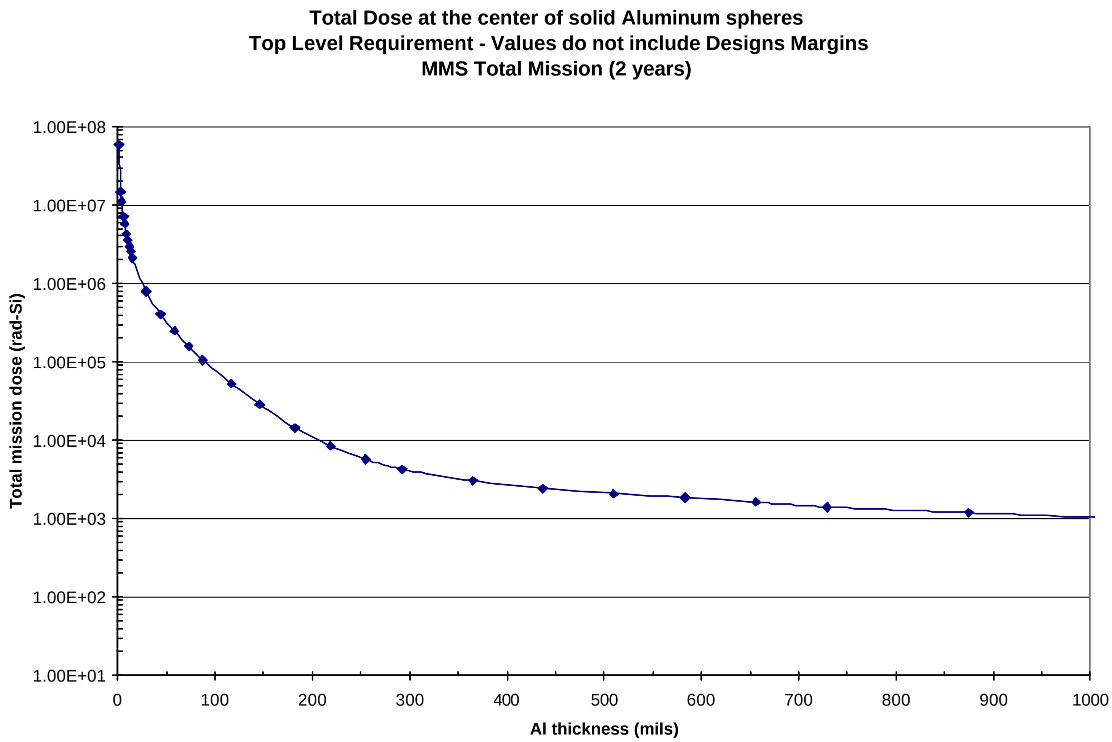

Figure 3-5. Total Dose-Depth Curve.

- The radiation design margin for a specific linear bipolar component can be reduced if it can be shown that for a specific vendor's component procurement lot that the component does not experience Enhanced Low Dose Rate susceptibility (ELDRS) and/or DDD effects.

- If a device's performance degradation due to TID is not acceptable using the top-level shielding requirement of 100 mils then the space radiation environments will be estimated using a more accurate methods such as solid angle sectoring/3-dimensional ray trace. This can significantly reduce the estimated TID requirement.

A design's resistance to component performance degradation due to TID for the specified radiation environment must be demonstrated.

1.2 Component Displacement Damage Dose (DDD) Specification

No effect due to DDD may cause permanent damage to or degradation of a system or subsystem.

Components or circuits shall be designed to be immune to performance degradation due to DDD such that if this degradation were to occur it would induce system or subsystem functional failures, anomalies, or outages which are catastrophic or require ground intervention to be corrected. A component shall be defined as immune if its parametrics and functionality remain unchanged after 4×10^{12} protons/cm^2 of 10 MeV protons, as demonstrated by proton testing.

Each component must be assessed for potential sensitivity to DDD effects. For those components deemed sensitive to DDD, if component test data does not exist, ground testing is required. For commercial components, if testing is required it must be preformed on the flight procurement lot. All testing must be performed using protons to a mission equivalent fluence.

For any component that is estimated to have on-orbit performance degradation due to DDD, an analysis must be performed to show that this degradation does not cause damage to or induce-degradation of system or subsystem performance. Alternatively, protective circuitry must be added to eliminate the possibility of damage to or degradation of system or subsystem performance, and verified by analysis or test.

DDD environment specifications (top-level shielding is assumed to be 100 mils equivalent Al):

- The top-level DDD requirement to be used for analysis for the 2 years MMS mission is given in Figure 3-6 and Table A-2.

- A radiation design margin of 2 will be used on all environment estimates when considering their effects on component performance.

- From top level DDD mission equivalent proton fluence behind 100 mils equivalent Al shielding, the top level DDD requirement is 8E10 p/cm2 of 10 MeV protons.

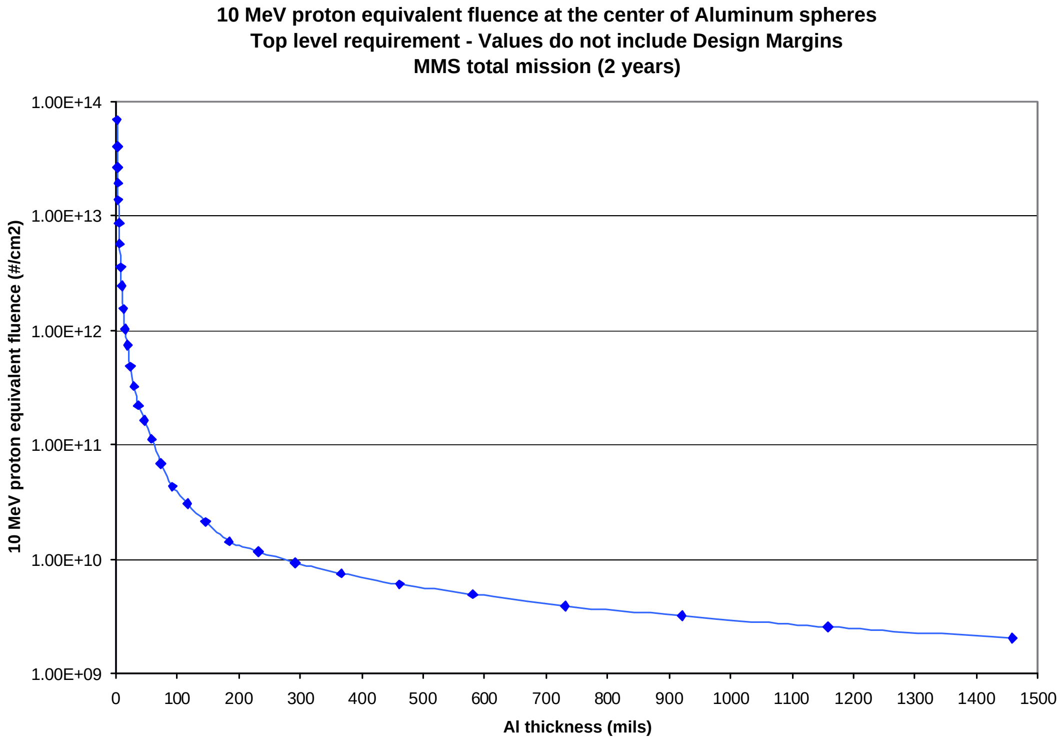

Figure 3-6 : 10 MeV proton equivalent fluence curve

- If a device's performance degradation due to DDD is not acceptable using the top level requirements, then the space radiation environment on this device will be estimated using a more accurate method such as solid angle sectoring/3-dimensional ray trace. This can significantly reduce the estimated DDD.

A design's resistance to component performance degradation due to DDD for the specified radiation environment must be demonstrated.

1.3 Single Event Effects (SEE) specification

1.3.1 Definitions

Linear Energy Transfer (LET) - a measure of the energy deposited per unit length as a energetic particle travels through a material. The common LET unit is MeV*cm^2/mg of material (Si for MOS devices, etc.).

Threshold LET (LET_{th}) - the minimum LET to cause an effect at a particle fluence of 1E7 ions/cm^2. Typically, a particle fluence of 1E5 ions/cm^2 is used for SEB and SEGR testing.

1.3.2 Component SEE Specification

No SEE may cause permanent damage to a system or subsystem.

Electronic components shall be designed to be immune to SEE induced performance anomalies, or outages which require ground intervention to correct. Electronic component reliability shall be met in the SEE environment. Immunity is defined as an LETth > 100 MeVcm^2/mg, which must be shown by heavy ion testing or analysis.

If component test data does not exist, ground testing is required. For commercial components, testing is required on the flight procurement lot.

For any component that is not immune to SEL or other potentially destructive conditions, protective circuitry must be added to eliminate the possibility of damage to or degradation of system or subsystem performance. The effectiveness of the protective circuitry must be verified by analysis or test.

For single particle events like SEU, SET, and MBU the *criticality* of a component in it's specific application must be defined into one of three categories: *error-critical*, *error-functional*, or *error-vulnerable*. Please refer to the Single Event Effect Criticality Analysis (SEECA) document for details. A SEECA analysis should be performed at the system level. After defining the component application into a category each component must be defined into an outage class.

Component heavy-ion and proton testing (and from these a rate calculation) must be preformed on each application of each component that falls into categories and classes defined below. Rates will be computed for peak and ambient conditions for the space radiation environments.

SEE testing and anlysis to determine SEE rates must take place based on LET_{th} of the candidate devices as follows:

Device Threshold	**Environment to be Assessed**
LET_{th} < 12 MeV*cm2/mg	Cosmic Ray, Trapped Protons, Solar Proton Events
LET_{th} = 12-100 MeV*cm2/mg	Galactic Cosmic Ray Heavy Ions, Solar Heavy Ions
LET_{th} > 100 MeV*cm2/mg	No analysis required

Table 3-13 Environment to be assessed based on SEE Device LET Threshold

SEE environment specification (recall top level shielding is 100 mils equivalent Al): A radiation design margin of 2 will be used on all environment estimates when considering their effects on component performance.

- The cosmic ray integral-flux LET spectrum to be used for analysis is given in Figure 3-7 and Table A3. Due to the 2006 launch date the solar minimum spectrum should be used.

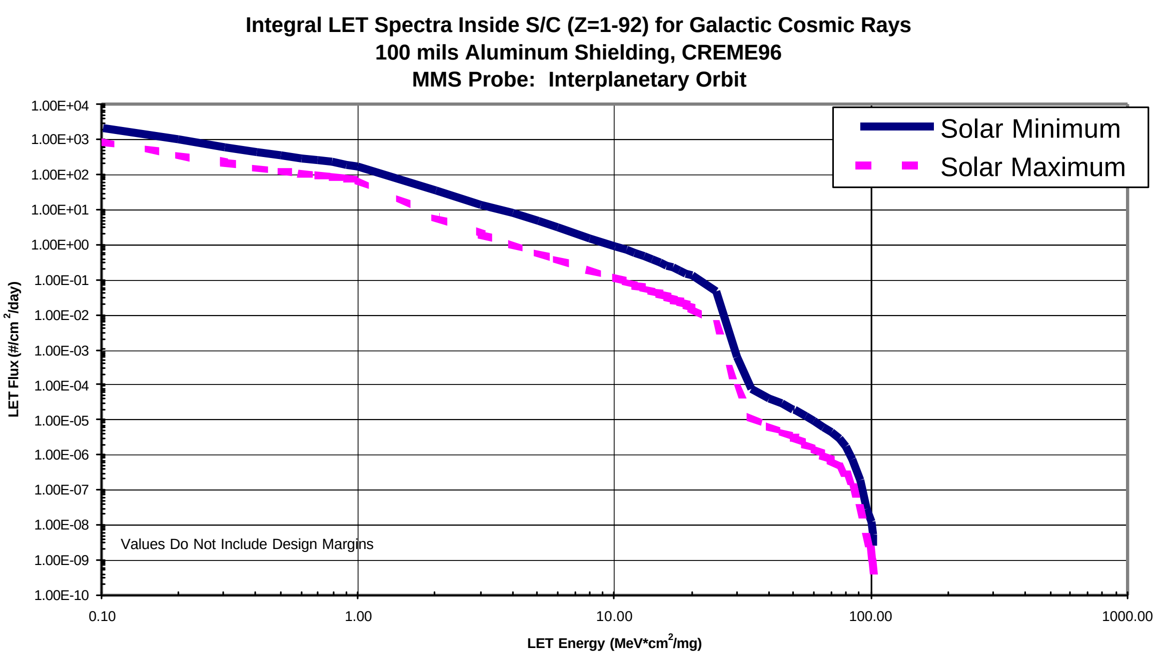

Fig 3-7 GCR LET spectra

- The solar particle event integral-flux LET spectrum to be used for analysis is given in Figure 3-8 and Table A4.

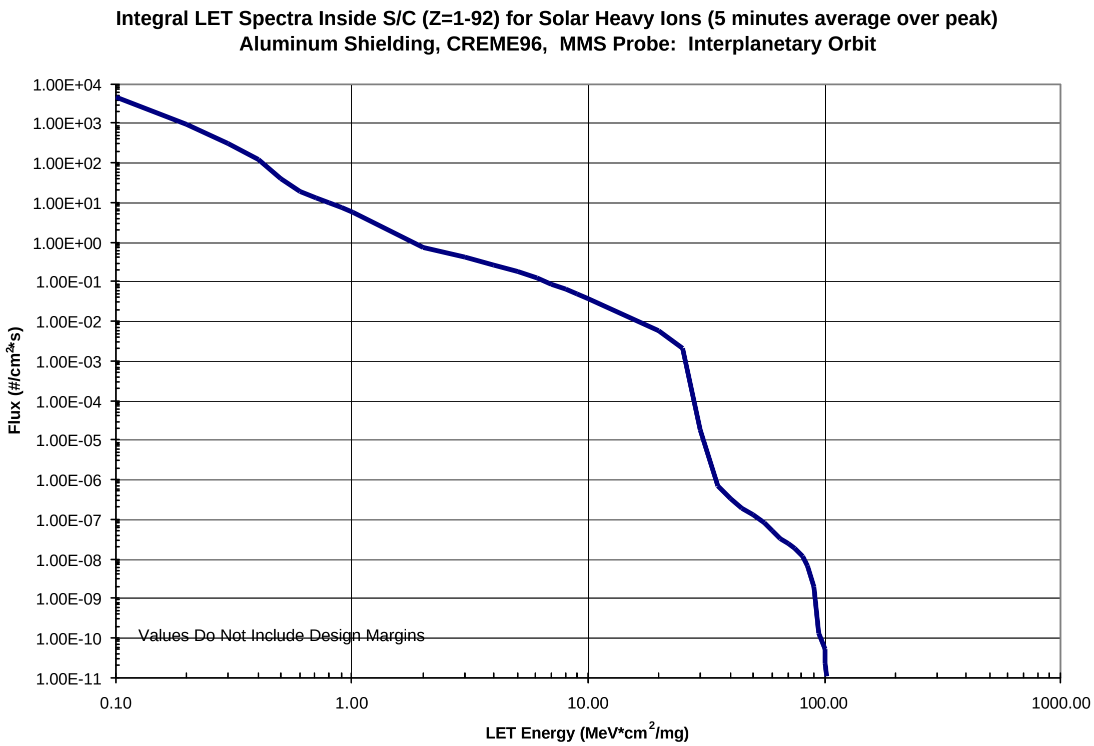

Figure 3.8 : Solar Particle Event Integral Flux LET spectrum

- The solar proton energy spectrum to be used for analysis is given in Figure 3-9 and Table A5.

- The daily average and peak trapped proton energy spectra to be used for analysis is given in Figure 3-10 and Table A6. The daily average flux corresponds to daily proton flux during the Phase 1 of the MMS mission. The peak particle flux corresponds also to the peak particle flux during the Phase 1 of the MMS mission. The Phase1 is the most exposed Phase to the trapped proton environment.

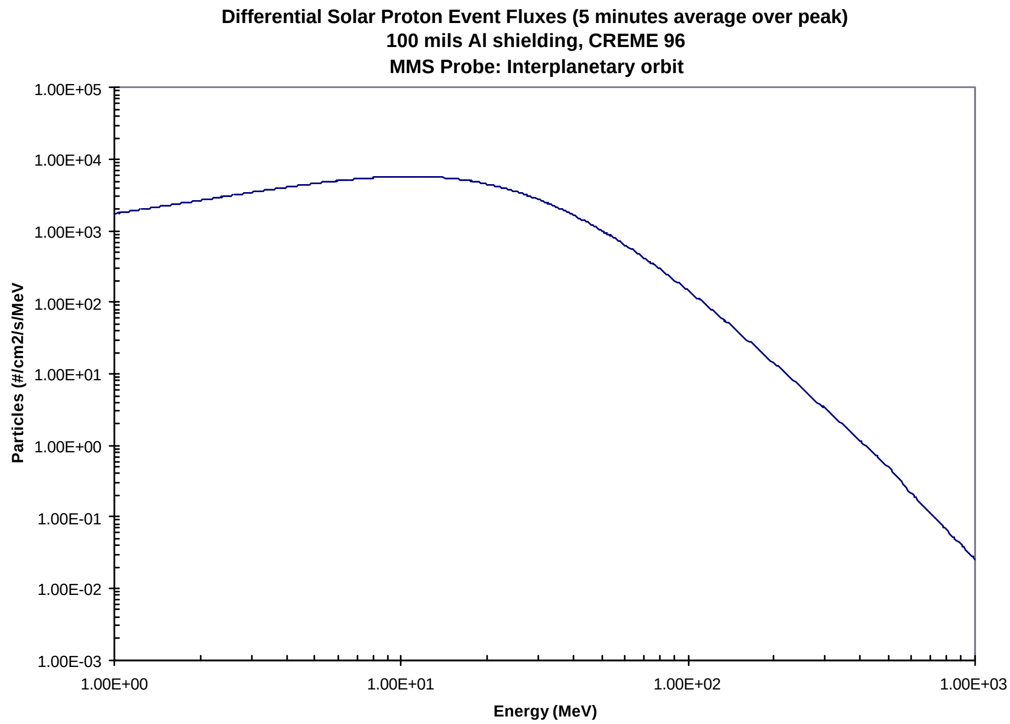

Figure 3.9: shielded solar proton energy spectrum for 100 mils Al (October 1989 event)

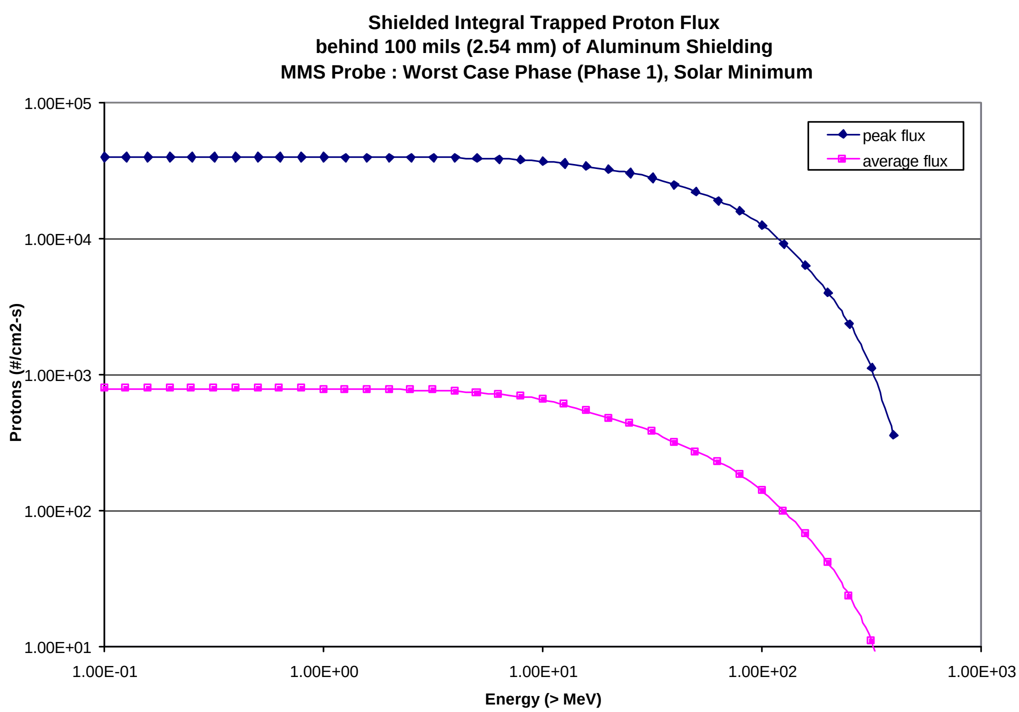

Fig 3-10: Trapped Proton Energy-flux spectrum

The improper operation caused by single particle event like SEU, SET and MBU shall be reduced to acceptable levels. Systems engineering analysis of circuit design, operating modes, duty cycle, device criticality etc. shall be used to determine acceptable levels for that device. Means of gaining acceptable levels include part selection, error detection and correction schemes, redundancy and voting methods, error tolerant coding, or acceptance of errors in non-critical areas.

A design's resistance to SEE for the specified radiation environment must be demonstrated.

2 Appendices

Table A1

Total Ionizing Dose at the Center of Aluminum Spheres,

2 years MMS mission (10 months Phase1, 4 months Phase2, 3 months Phase3, 6 months Phase 4)

Values Do not include Design Margins

Aluminum Shield Thickness			Total dose
mils	**cm**	**g/cm^2**	**rad-Si**
1	0.003	0.007	5.87E+07
3	0.008	0.021	1.48E+07
4	0.010	0.027	1.12E+07
6	0.015	0.041	7.08E+06
7	0.018	0.048	5.77E+06
9	0.023	0.062	4.21E+06
10	0.025	0.069	3.61E+06
12	0.030	0.082	2.94E+06
13	0.033	0.089	2.61E+06
15	0.038	0.103	2.14E+06
29	0.074	0.199	7.86E+05
44	0.112	0.302	4.04E+05
58	0.147	0.398	2.49E+05
73	0.185	0.501	1.57E+05
87	0.221	0.597	1.05E+05
117	0.297	0.802	5.25E+04
146	0.371	1.001	2.86E+04
182	0.462	1.248	1.43E+04

Table A1 (continued)

Total Ionizing Dose at the Center of Aluminum Spheres,

2 years MMS mission (10 months Phase1, 4 months Phase2, 3 months Phase3, 6 months Phase 4)

Values Do not include Design Margins

Aluminum Shield Thickness			**Total dose**
mils	**cm**	**g/cm^2**	**rad-Si**
219	0.556	1.502	8.52E+03
255	0.648	1.749	5.73E+03
292	0.742	2.003	4.27E+03
365	0.927	2.503	3.04E+03
437	1.110	2.997	2.41E+03
510	1.295	3.498	2.08E+03
583	1.481	3.998	1.86E+03
656	1.666	4.499	1.62E+03
729	1.852	4.999	1.40E+03
875	2.223	6.001	1.19E+03
1167	2.964	8.003	9.02E+02
1458	3.703	9.999	7.19E+02

Table A2

10 MeV proton equivalent fluence at the Center of Aluminum Spheres,

2 years MMS mission (10 months Phase1, 4 months Phase2, 3 months Phase3, 6 months Phase 4)

Values Do not include Design Margins

Aluminum Shield Thickness			**10 MeV proton equivalent Fluence**
mils	**mm**	**g/cm2**	**#/cm2**
1.46	0.04	0.01	1.51E+00
1.84	0.05	0.01	1.89E+00
2.31	0.06	0.02	2.39E+00
2.91	0.07	0.02	3.00E+00
3.66	0.09	0.03	3.78E+00
4.61	0.12	0.03	4.76E+00
5.81	0.15	0.04	5.99E+00
7.31	0.19	0.05	7.54E+00
9.20	0.23	0.06	9.50E+00
11.58	0.29	0.08	1.20E+01
14.58	0.37	0.10	1.51E+01
18.36	0.47	0.13	1.89E+01
23.11	0.59	0.16	2.39E+01
29.09	0.74	0.20	3.00E+01
36.63	0.93	0.25	3.78E+01
46.11	1.17	0.32	4.76E+01
58.05	1.47	0.40	5.99E+01
73.08	1.86	0.50	7.54E+01
92.00	2.34	0.63	9.50E+01
115.83	2.94	0.79	1.20E+02
145.82	3.70	1.00	1.51E+02
183.57	4.66	1.26	1.89E+02

Table A2 (continued)

10 MeV proton equivalent fluence at the Center of Aluminum Spheres,

2 years MMS mission (10 months Phase1, 4 months Phase2, 3 months Phase3, 6 months Phase 4)

Values Do not include Design Margins

Aluminum Shield Thickness			**10 MeV proton equivalent Fluence**
mils	**mm**	**g/cm2**	**#/cm2**
231.10	5.87	1.59	2.39E+02
290.94	7.39	2.00	3.00E+02
366.27	9.30	2.51	3.78E+02
461.11	11.71	3.16	4.76E+02
580.50	14.74	3.98	5.99E+02
730.81	18.56	5.01	7.54E+02
920.03	23.37	6.31	9.50E+02
1158.30	29.42	7.94	1.20E+03
1458.20	37.04	10.00	1.51E+03

Table A3

Integral LET for Interplanetary Galactic Cosmic Rays (Z=1-92)

100 mils Aluminum shielding

Values does not include Design Margins

LET (MeV*cm^2/mg)	**LET Fluence (#/cm^2/day) Solar Minimum**	**LET Fluence (#/cm^2/day) Solar Maximum**
0.10	2.23E+03	8.74E+02
0.20	9.84E+02	3.59E+02
0.30	6.35E+02	2.32E+02
0.40	4.33E+02	1.52E+02
0.50	3.42E+02	1.24E+02
0.60	2.90E+02	1.10E+02
0.70	2.50E+02	9.66E+01
0.80	2.23E+02	8.84E+01
0.90	1.98E+02	7.94E+01
1.00	1.79E+02	7.22E+01
2.01	3.39E+01	5.88E+00
3.02	1.43E+01	2.03E+00
3.99	7.76E+00	1.02E+00
5.03	4.59E+00	5.81E-01
5.99	3.07E+00	3.80E-01
8.00	1.55E+00	1.90E-01
10.09	9.00E-01	1.10E-01
11.07	7.17E-01	8.74E-02
12.01	5.76E-01	7.04E-02
13.02	4.67E-01	5.71E-02

Table A3 (continued)

Integral LET for Interplanetary Galactic Cosmic Rays (Z=1-92)

100 mils Aluminum shielding

Values does not include Design Margins

LET **MeV*cm^2/mg**	**LET Fluence** **#/cm^2/day** **Solar Minimum**	**LET Fluence** **#/cm^2/day** **Solar Maximum**
13.96	3.85E-01	4.72E-02
14.97	3.16E-01	3.88E-02
16.05	2.61E-01	3.20E-02
17.00	2.20E-01	2.71E-02
18.02	1.85E-01	2.27E-02
19.09	1.54E-01	1.89E-02
20.00	1.30E-01	1.60E-02
24.93	4.45E-02	5.49E-03
30.01	6.27E-04	8.18E-05
34.10	7.67E-05	1.18E-05
40.11	4.18E-05	6.49E-06
45.04	2.83E-05	4.42E-06
49.99	2.00E-05	3.13E-06
50.58	1.92E-05	3.00E-06
55.49	1.34E-05	2.11E-06
60.19	9.38E-06	1.49E-06
65.28	6.32E-06	1.01E-06
69.98	4.40E-06	7.01E-07
75.02	2.83E-06	4.52E-07

Table A3 (continued)

Integral LET for Interplanetary Galactic Cosmic Rays (Z=1-92)

100 mils Aluminum shielding

Values does not include Design Margins

LET **MeV*cm^2/mg**	**LET Fluence** **#/cm^2/day** **Solar Minimum**	**LET Fluence** **#/cm^2/day** **Solar Maximum**
80.43	1.65E-06	2.63E-07
85.23	7.71E-07	1.23E-07
90.32	1.94E-07	3.10E-08
95.71	2.88E-08	4.60E-09
100.25	1.19E-08	1.89E-09
101.42	5.27E-09	8.41E-10
102.61	2.54E-09	4.05E-10

Table A4

Integral LET for the October 1989 Solar Particle Event (Z=1-92)

100 mils Aluminum shielding

Values do not include Design Margins

LET ($MeV*cm^2/mg$)	LET Flux ($\#/cm^2*s$) Average Over Peak
0.10	4.77E+03
0.20	9.50E+02
0.30	3.15E+02
0.40	1.25E+02
0.50	3.82E+01
0.60	1.86E+01
0.70	1.35E+01
0.81	9.85E+00
0.90	7.55E+00
1.00	5.88E+00
2.01	7.49E-01
3.02	4.11E-01
3.99	2.64E-01
5.03	1.74E-01
6.06	1.21E-01
7.04	8.68E-02
8.00	6.39E-02
8.99	5.04E-02
10.09	3.85E-02
20.00	5.75E-03
25.22	2.14E-03

Table A4 (continued)

Integral LET for the October 1989 Solar Particle Event (Z=1-92)

100 mils Aluminum shielding

Values do not include Design Margins

LET ($MeV*cm^2/mg$)	LET Flux ($\#/cm^2*s$) Average Over Peak
30.01	1.83E-05
35.30	7.23E-07
40.11	3.26E-07
45.04	1.95E-07
49.99	1.36E-07
55.49	8.43E-08
60.19	4.92E-08
65.28	3.28E-08
69.98	2.49E-08
75.02	1.80E-08
80.43	1.20E-08
85.23	6.69E-09
90.32	2.03E-09
94.61	1.33E-10
100.25	5.01E-11
101.42	2.22E-11
102.61	1.07E-11

Table A5

Differential Fluxes from Solar Proton Events

100 mils Al Shielding, CREME 96

5 minutes average over peak

Values do not include Design Margins

Energy (MeV)	**Proton flux (#c/m2-s-MeV) average over Peak**
1.00	1.75E+03
2.00	2.68E+03
3.02	3.47E+03
4.04	4.11E+03
5.04	4.62E+03
6.03	5.03E+03
7.02	5.33E+03
8.06	5.56E+03
9.00	5.69E+03
10.47	5.77E+03
14.99	5.41E+03
20.03	4.50E+03
24.98	3.57E+03
30.31	2.73E+03
35.27	2.11E+03
40.49	1.61E+03
50.50	9.91E+02
60.43	6.33E+02

Table A5 (continued)

Differential Fluxes from Solar Proton Events

100 mils Al Shielding, CREME 96

5 minutes average over peak

Values do not include Design Margins

Energy (MeV)	**Proton flux (#c/m2-s-MeV) average over Peak**
70.33	4.20E+02
79.63	2.94E+02
90.17	2.03E+02
100.69	1.44E+02
150.25	3.84E+01
200.77	1.39E+01
299.59	3.32E+00
400.31	1.16E+00
499.23	4.97E-01
605.64	2.07E-01
704.94	1.10E-01
798.17	6.61E-02
903.74	3.95E-02
995.41	2.65E-02

Table A6

Trapped Proton Integral Fluxes

100 mils Al shielding

Values do not include Design margins

Energy **E> MeV**	**Average Flux** **#/cm2-s**	**Peak Flux** **#/cm2-s**
0.04	7.84E+02	3.94E+04
0.05	7.84E+02	3.94E+04
0.06	7.84E+02	3.94E+04
0.08	7.82E+02	3.94E+04
0.10	7.82E+02	3.94E+04
0.13	7.82E+02	3.94E+04
0.16	7.82E+02	3.94E+04
0.20	7.82E+02	3.94E+04
0.25	7.82E+02	3.94E+04
0.32	7.82E+02	3.94E+04
0.40	7.82E+02	3.94E+04
0.50	7.81E+02	3.94E+04
0.63	7.81E+02	3.94E+04
0.79	7.80E+02	3.94E+04
1.00	7.79E+02	3.94E+04
1.26	7.78E+02	3.93E+04
1.58	7.75E+02	3.93E+04
2.00	7.72E+02	3.92E+04
2.51	7.67E+02	3.91E+04
3.16	7.60E+02	3.90E+04
3.98	7.50E+02	3.88E+04

Table A6 (continued)

Trapped Proton Integral Fluxes

100 mils Al shielding

Values do not include Design margins

Energy **E> MeV**	**Average flux** **#/cm2-s**	**Peak flux** **#/cm2-s**
5.01	7.35E+02	3.85E+04
6.31	7.15E+02	3.81E+04
7.94	6.90E+02	3.75E+04
10.00	6.52E+02	3.66E+04
12.60	6.01E+02	3.53E+04
15.80	5.35E+02	3.36E+04
20.00	4.78E+02	3.18E+04
25.10	4.32E+02	3.00E+04
31.60	3.77E+02	2.77E+04
39.80	3.18E+02	2.48E+04
50.10	2.71E+02	2.20E+04
63.10	2.27E+02	1.89E+04
79.40	1.83E+02	1.58E+04
100.00	1.39E+02	1.24E+04
126.00	9.92E+01	9.07E+03
158.00	6.67E+01	6.26E+03
200.00	4.14E+01	3.99E+03
251.00	2.35E+01	2.33E+03
316.00	1.10E+01	1.11E+03
398.00	3.45E+00	3.58E+02